DOCUMENT RESUME

ED 151 2?? SE 024 004

AUTHOR	Bengston, Harlan H.
TITLE	Advanced Hydraulics for Operators. Training Module 1.331.3.77.
INSTITUTION	Kirkwood Community Coll., Cedar Rapids, Iowa.
SPONS AGENCY	Department of Labor, Washington, D.C.; Iowa State Dept. of Environmental Quality, Des Moines.
PUB DATE	Sep 77
NOTE	59p.; For related documents, see SE 022 996-SE 024 003; Contains occasional light and broken type
EDRS PRICE	MF-$0.83 HC-$3.50 Plus Postage.
DESCRIPTORS	*Hydraulics; *Instructional Materials; *Physics; *Post Secondary Education; Secondary Education; *Teaching Guides; Units of Study; Water Pollution Control
IDENTIFIERS	*Pumps; Waste Water Collection; *Waste Water Treatment

ABSTRACT

This document is an instructional module package prepared in objective form for use by an instructor familiar with the application of hydraulic principles to water supply and water pollution control systems including water distribution systems and sewer systems. Included are objectives, instructor guides, student handouts and transparency masters. This is the second level of a two module series. Presented are aspects of hydrostatics, Bernoullis equation and energy relationships for flow systems including frictional losses and pump work input, hydraulic models of flowthrough tanks; and overall hydraulic analysis of systems. (Author/RH)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED151211

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Mary Jo Bruett

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) AND USERS OF THE ERIC SYSTEM."

ADVANCED HYDRAULICS FOR OPERATORS

Training Module 1.331.3.77

Prepared for the

Iowa Department of Environmental Quality
Wallace State Office Building
Des Moines, Iowa 50319

by

Harlan H. Bengston
Environmental Resources Training Center
Southern Illinois University at Edwardsville
Edwardsville, Illinois 62026

The publication of these training materials was financially aided through a contract between the Iowa Department of Environmental Quality and the Office of Planning and Programming, using funds available under the Comprehensive Employment and Training Act of 1973. However, the opinions expressed herein do not necessarily reflect the position or policy of the U. S. Department of Labor, and no official endorsement by the U. S. Department of Labor should be inferred.

September, 1977

SE 024 004

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title:
Approx. Time 16 hours	Topic: Advanced principles of hydraulics and their application to water and wastewater systems operation.

Instructional Objective:

To gain familiarity with the general principles and gain the ability to make calculations in the following areas: hydrostatics; Bernoulli's equation and energy relationships, including frictional losses and pump work; hydraulic models of flow through tanks; and overall hydraulic analysis of systems.

Instructional Aids: Handouts No. F.1.1, F.1.2, F.1.3, F.2.1, F.2.2, F.2.3, F.3.1, F.3.2, G.1.1, G.2.1, G.3.1, G.3.2, G.4.1, G.4.2, G.5.1, G.5.2, H.1.1, H.2.1, I.1.1, I.2.1, I.2.2

Transparencies No. F.2.1, G.1.1, G.2.1, H.1.1, I.2.1

Instructional Approach:

Lecture, Discussion, Problem Session

References:

See next sheet

Class Assignments: Completion of practice problems which aren't finished in class.

REFERENCES

1) Clark, J.W., Viessman, W., Jr., & Hammer, M.J., Water Supply and Pollution Control, 3rd Ed., IEP, New York, N.Y., 1977.

2) John, J.E.A., and Haberman, W., Introduction to Fluid Mechanics, Prentice Hall, Englewood Cliffs, N.J., 1971.

3) Levenspiel, O., Chemical Reaction Engineering, 2nd Ed., Wiley, New York, N.Y., 1972.

4) Murdock, J.W., Fluid Mechanics and its Applications, Houghton Mifflin, Boston, Mass., 1976.

5) Plapp, J.E., Engineering Fluid Mechanics, Prentice-Hall, Englewood Cliffs, N.J., 1968.

6) Simon, A.L., Practical Hydraulics, Wiley, New York, N.Y., 1976.

7) U.S. Environmental Protection Agency, Process Design Manual for Suspended Solids Removal, U.S. EPA Technology Transfer, Cincinnati, Ohio, 1975.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title: Hydrostatics
Approx. Time 1 hour	Topic: Pressure Dependence on Depth

Instructional Objective:

To be able to calculate the pressure at any given depth below the surface of a body of water or some other liquid of known specific weight.

Instructional Aids: Handouts No. F.1.1, F.1.2, F.1.3

Instructional Approach:

Discussion and problem session

References:
1) Simon, A.L. p. 31
2) Murdock, J.W. pp. 52-54
3) John, J.E.A. & Haberman, W. pp. 349-350

Class Assignments: Complete any practice problems not finished in class.

Module No: 13MG	Topic: Pressure Dependence on Depth

Instructor Notes:	Instructor Outline:
Handout No. F.1.1 Pressure-Depth Relationships Handout No. F.1.2 Practice Problems - 1 Handout No. F.1.3 Conversion Factors	I. Discuss the relationship between pressure and depth in a liquid as outlined on the handout. II. Allow students to work out the practice problems, giving individual help as required.

Module No:	Module Title: Advanced Hydraulics for Operators
I3MG	Submodule Title: Hydrostatics
Approx. Time 1 ½ hours	Topic: Force on a Submerged Surface

Instructional Objective:

To be able to calculate the force of water on a submerged horizontal surface of known surface area and depth or on the submerged portion of a vertical rectangular surface or a vertical surface of any shape with specified surface area and specified centroid location.

Instructional Aids: Handouts No. F.2.1, F.2.2, F.2.3

Transparency No. F.2.1

Instructional Approach: Discussion and Problem Session

References:
1) Simon, A.L., pp. 31-40
2) Murdock, J.W., pp. 68-74
3) John, J.E.A. & Haberman, W., pp. 355-361

Class Assignments: Complete any practice problems which weren't finished in class.

Module No: I3MG	Topic: Force on a Submerged Surface

Instructor Notes:	Instructor Outline:
Transparency No. F.2.1 Force on a Submerged Surface Handout No. F.2.1 Force on a Submerged Surface Handout No. F.2.2 Properties of Plane Surfaces Handout No. F.2.3 Practice Problems - 2	I. Discuss forces on submerged horizontal and vertical surfaces as outlined on the transparency and Handout No. F.2.1. This should include a discussion of the centroid of a plane surface and the use of Handout No. F.2.2 to find centroids of given surfaces. II. Allow the class to work out the practice problems, giving individual help as required.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title:
Approx. Time	Hydrostatics
1 hour	Topic: Manometers

Instructional Objective:

To be able to calculate the pressure difference measured by a manometer if given the difference in height of the manometer fluid in the two legs, the specific weight of the manometer fluid and the density of the measured fluid.

Instructional Aids: Handouts No. F.3.1, F.3.2

Instructional Approach: Discussion and problem session

References:
1) Simon, A.L., pp. 249-253
2) Murdock, J.W., pp. 55-61
3) John, J.E.A. & Haberman, W., pp. 351-355

Class Assignments: Complete any practice problems which weren't finished in class.

Module No: I3MG	Topic: Manometers

Instructor Notes:	Instructor Outline:
Handout No. F.3.1 Manometers Handout No. F.3.2 Practice Problems - 3	I. Discuss measurement of pressure and pressure differences with a manometer as outlined on the handout. II. Allow students to work on the practice problems, giving help as required.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title: Bernoulli's Equation
Approx. Time 1 hour	Topic: Conservation of Energy

Instructional Objective:

To be able to state the conditions under which Bernoulli's Equation is applicable and decide whether or not it is applicable from a description of the system.

Instructional Aids: Transparency No. G.1.1

Handouts No. G.1.1

Instructional Approach: Discussion

References:
1) Simon, A.L., pp. 25-28
2) Murdock, J.W., pp. 125-127
3) John, J.E.A. & Haberman, W., pp. 42-44

Class Assignments: None

Module No: I3MG	Topic: Conservation of Energy

Instructor Notes:	Instructor Outline:
Transparency No. G.1.1 Bernoulli's Equation Handout No. G.1.1 Conservation of Energy	Discuss the relationship of Bernoulli's equation to the principle of conservation of energy and discuss the type of system to which Bernoulli's equation applies.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title: Bernoulli's Equation
Approx. Time 1 hour	Topic: Types of "Heads"

Instructional Objective:

To be able to define and write mathematical expressions for each of the following: position head, velocity head, pressure head.

Instructional Aids: Handout No. G.2.1

Transparency No. G.2.1

Instructional Approach: Discussion

References:
1) Simon, A.L., pp. 25-28
2) Murdock, J.W., pp. 125-127

Class Assignments: None

Module No: I3MG	Topic: Types of "Heads"

Instructor Notes:	Instructor Outline:
Handout No. G.2.1 Types of "Heads" Transparency No. G.2.1 Types of "Heads"	I. Discuss velocity head, pressure head, and position head and their interpretation as outlined on the handout and transparency. II. If facilities are available a demonstration of water flowing through a pipe or tube with a static pressure probe and a dynamic pressure probe as shown on the transparency would be helpful.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title: Bernoulli's Equation
Approx. Time	
1 ½ hours	Topic: Bernoulli Equation Calculations

Instructional Objective:

To be able to use Bernoulli's equation to calculate pressure, velocity, or height of an inlet or outlet stream for a system if the other two for that stream and all three for the other stream are either specified or can be eliminated from the equation.

Instructional Aids: Handouts No. G.3.1, G.3.2

Instructional Approach: Discussion and problem session

References:
1) Simon, A.L., pp. 26-28
2) Murdock, J.W., pp. 126-127
3) John, J.E.A. & Haberman, W., pp. 45-49

Class Assignments: Complete any practice problems not finished in class.

Module No: 13MG	Topic: Bernoulli Equation Calculations

Instructor Notes:	Instructor Outline:
Handout No. G.3.1 Bernoulli Equation Calculations Handout No. G.3.2 Practice Problems - 3	I. Discuss Bernoulli Equation calculations and example on handout. II. Allow students to work on the practice problems, providing individual help as required.

Module No:	Module Title: Advanced Hydraulics for Operators
13MG	
	Submodule Title: Bernoulli's Equation
Approx. Time	
1 ½ hours	Topic: Pump Work and Efficiency

Instructional Objective:

To be able to calculate the energy input to a pump, the energy output from the pump, or the pump efficiency if given values for the other two; and to be able to calculate power input, head input or mass flow rate if given values for the other two.

Instructional Aids: Handouts No. G.4.1, G.4.2

Instructional Approach: Discussion and problem session

References: 1) Murdock, J.W., pp. 133-135

Class Assignments: Complete any practice problems not finished in class.

Module No: I3MG	Topic: Pump Work and Efficiency

Instructor Notes:	Instructor Outline:
Handout No. G.4.1 Pump Work and Efficiency	I. Discuss the relationship among energy input to a pump, energy imparted to water by the pump, and efficiency of the pump, as outlined on the handout.
Handout No. G.4.2 Practice Problems - 4	II. Allow students to work out the practice problems, giving individual help as required.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title: Bernoulli's Equation
Approx. Time 1 ½ hours	Topic: Modified Bernoulli's Equation

Instructional Objective:

To be able to use a modified Bernoulli's equation containing terms for frictional head loss and pump work head to calculate a value for one unknown variable in the equation if all of the others are specified or can be eliminated.

Instructional Aids: Handouts No. G.5.1, G.5.2

Instructional Approach: Discussion and problem session

References: 1) Simon, A.L., pp. 25-28
2) Murdock, J.W. pp. 149-152

Class Assignments: Complete any practice problems not finished in class.

Module No: I3MG	Topic: Modified Bernoulli's Equation

Instructor Notes:	Instructor Outline:
Handout No. G.5.1 Modified Bernoulli's Equation	I. Discuss the use of pump head and friction head terms in the Bernoulli equation in order to extend the applications of the equation.
Handout No. G.5.2 Practice Problems - 5	II. Allow students to work out the practice problems, giving individual help as required.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title: Hydraulic Models of Flow-through Tanks
Approx. Time 1 ½ hours	Topic: Plug Flow and Completely-Mixed Tanks

Instructional Objective:

To be able to compare the characteristics of an ideal completely-mixed tank with those of an ideal plug-flow tank, in general, and for the particular case of use as the aeration tank in an activated sludge process.

Instructional Aids: Handout No. H.1.1

Transparency No. H.1.1

Instructional Approach: Lecture and Discussion

References:
1) Clark, J.W., Viessman, W., Jr., & Hammer, M.J. pp. 338-343, 573-575, 579-580.
2) Levenspiel, O., pp. 97-98.

Class Assignments: None

Module No: I3MG	Topic: Plug Flow and Completely-Mixed Tanks

Instructor Notes:	Instructor Outline:
Handout No. H.1.1 Hydraulic Models for Tanks Transparency No. H.1.1 Hydraulic Models for Tanks	Discuss characteristics of plug flow and completely-mixed tanks in general and as applied to activated sludge aeration tanks. If necessary give additional background information about BOD and the activated sludge process.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title: Hydraulic Models of Flow-through Tanks
Approx. Time 1 ½ hours	Topic: Short Circuiting

Instructional Objective:

To be able to define short circuiting for flow through a tank, describe effects of short circuiting on clarifier performance, and list possible factors causing short circuiting in a clarifier.

Instructional Aids: Handout No. H.2.1

Instructional Approach: Lecture and discussion

References:
1) Clark, J.W., Viessman, W., Hammer, M.J. pp. 150 & 164-167
2) U.S. EPA, pp. 7-2 - 7-11

Class Assignments: None

Module No: I3M6	Topic: Short Circuiting
Instructor Notes:	**Instructor Outline:**
Handout No. H.2.1 Short Circuiting	Discuss short circuiting, its causes, and relationships with clarification. Some background information on types of clarifiers can be given as necessary.

Module No:	Module Title:
I3MG –	Advanced Hydraulics for Operators
	Submodule Title: Overall Hydraulic Analysis of Systems
Approx. Time 1 ½ hours	Topic: Definitions and Background

Instructional Objective:

To be able to define and write mathematical expressions for peizometric head and total head, and to be able to define hydraulic grade line and energy grade line.

Instructional Aids: Handout No. I.1.1

Transparency No. G.2.1

Instructional Approach: Lecture and discussion

References:
1) Simon, A.L., pp. 25-26
2) Murdock, J.W., pp. 327-328
3) Plapp, J.E., pp. 287-292

Class Assignments: None

Module No: I3MG	Topic: Definitions and Background

Instructor Notes:	Instructor Outline:
Handout No. I.1.1 Energy Grade Line Definitions Transparency No. G.2.1 Types of "Heads"	Discuss peizometric head, total head, hydraulic grade line, and energy grade line referring to the previous discussion of "heads" in connection with Bernoulli's equation.

Module No:	Module Title:
I3MG	Advanced Hydraulics for Operators
	Submodule Title: Overall Hydraulic Analysis of Systems
Approx. Time 1 ½ hours	Topic: Hydraulic Grade Line and Energy Grade Line

Instructional Objective:

To be able to sketch the hydraulic grade line and the energy grade line for described pipe and open channel systems.

Instructional Aids: Handouts No. I.2.1 and I.2.2

Transparency No. I.2.1

Instructional Approach: Discussion and problem session

References:
1) Simon, A.L., pp. 25-26
2) Plapp, J.E., pp. 287-292

Class Assignments: Complete any practice problems which weren't finished in class.

Module No: I3MC	Topic: Hydraulic Grade Line and Energy Grade Line

Instructor Notes:	Instructor Outline:
Handout No. H.2.1 Energy and Hydraulic Grade Lines Handout No. H.2.2 Practice Problems - 5	I. Discuss sketching of hydraulic grade lines and energy grade lines through the use of the examples on the handout. II. Allow students to work out the practice problems, giving individual help as required.

EXAM QUESTIONS

Pressure Dependence on Depth

1) What would be the gage pressure and absolute pressure at a depth of 12 feet below the surface of a tank of water?

2) What would be the gage pressure at a depth of 20 feet below the surface of a liquid with specific weight of 60 lb/ft^3?

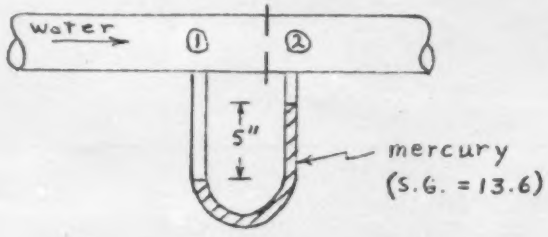
Force on a Submerged Surface

1) What would be the hydraulic force on a submerged horizontal surface 12 feet by 12 feet which is 15 feet below a water surface?

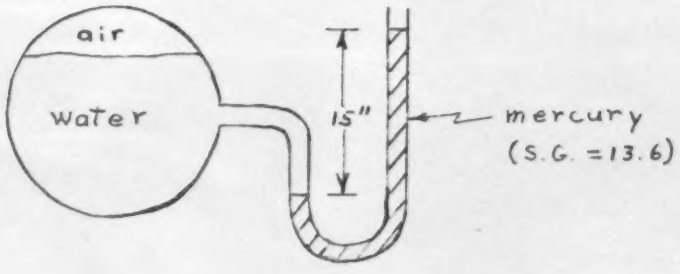
2) What would be the hydraulic force on a vertical 30 ft × 10 ft side of a tank if it is filled to a depth of 8 ft with water?

Manometers

1) What is the pressure difference between points 1 and 2 as indicated by the manometer below?



2) What is the gage pressure in psig in the tank shown below?



Conservation of Energy

1) What are three conditions which a system must satisfy if the simple form of Bernoulli's equation which follows is to be applied?

$$\frac{P_1}{\gamma} + h_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + h_2 + \frac{V_2^2}{2g}$$

2) Could the simple form of Bernoulli's equation which follows be applied to flow through 100 ft of pipe?

$$\frac{P_1}{\gamma} + h_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + h_2 + \frac{V_2^2}{2g}$$

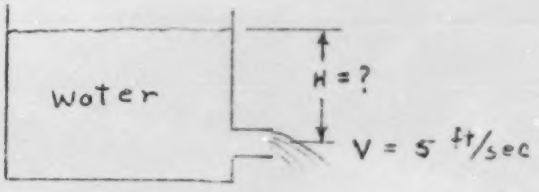
Types of "Heads"

1) Define and write a mathematical expression for each of the following?

i) velocity head
ii) position head
iii) pressure head

Bernoulli's Equation Calculations

1) What height would the water have to be in the tank shown below in order to cause an exit velocity of 5ft/sec? (neglect friction losses.)



2) Consider water flowing through the diffuser shown below. If V_1 = 15ft/sec, V_2 = 3ft/sec, and p_2 = 10psig, then what is p_1 in psig?

Pump Work and Efficiency

1) What is the efficiency of a pump which requires 8 horsepower input and delivers 6.5 horsepower to the water?

2) What would be the increase in head delivered to a flow of 100 lb/sec of water by a 70% efficient pump which uses power at the rate of 6 horsepower?

Modified Bernoulli's Equation

1) a) What head input from a pump would be needed to pump water from one open tank to another whose water level is 60 ft above the first? Consider the frictional head loss in the piping to be 3 ft.

   b) If the flow rate is to be 500 gpm and the pump has an efficiency of 75%, what horsepower would be needed to drive the pump?

2) Consider water flowing through a pipe from a reservoir to the inlet to a water treatment plant which is 60 ft lower than the reservoir surface level. If the frictional head loss in the pipe is 5 ft and the velocity in the pipe is 8 ft/sec, then what pressure could the water develop where it enters the plant?

Plug Flow and Completely-Mixed Tanks

1) Briefly compare the flow characteristics of an ideal plug flow tank with those of an ideal completely-mixed tank.

2) What type of tank should be used to give approximately plug flow and what type would give approximately completely-mixed flow?

3) What are the main effects of using a completely-mixed aeration tank instead of plug flow for an activated sludge process?

Short Circuiting

1) What is meant by short circuiting in connection with flow through a tank?

2) What are three possible causes for short circuiting in a clarifier?

3) Why is short circuiting undesireable in a clarifier?

Definitions and Background

1) What is meant by each of the following in connection with water flowing through a pipe or open channel?

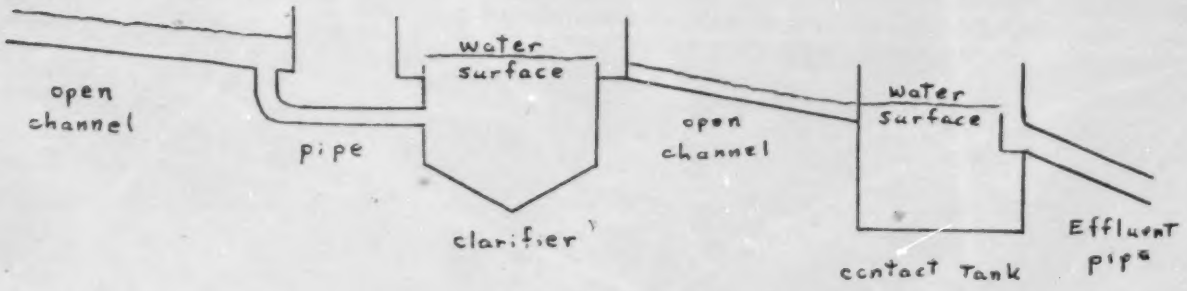
   a) peizometric head
   b) total head

2) What is meant by the hydraulic grade line for flowing water?

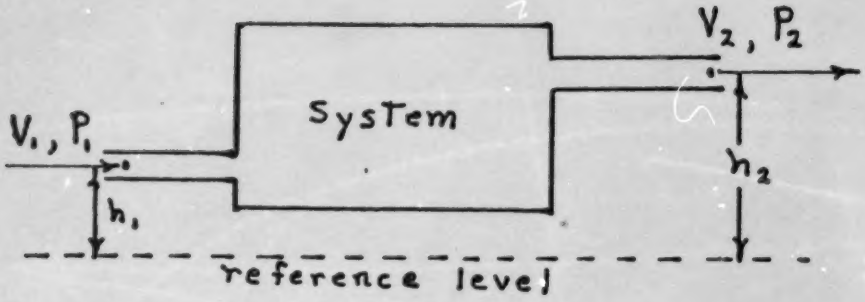
3) What is meant by the energy grade line for flowing water?

Hydraulic Grade Line and Energy Grade Line

1) Sketch the hydraulic grade line and the energy grade line on the diagram below. Be sure to clearly identify which is which.



BERNOULLI'S EQUATION



Conservation of Energy:

Rate of Energy Flow into System = Rate of Energy Flow out of System

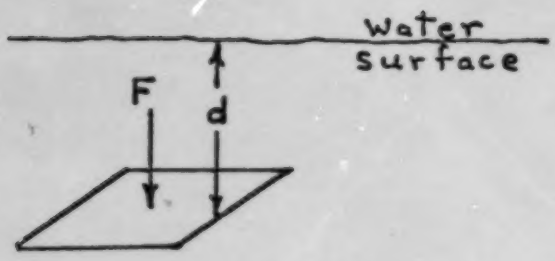
Bernoulli's Equation:

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + h_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_2$$

No. G. 1.1

FORCE ON A SUBMERGED SURFACE

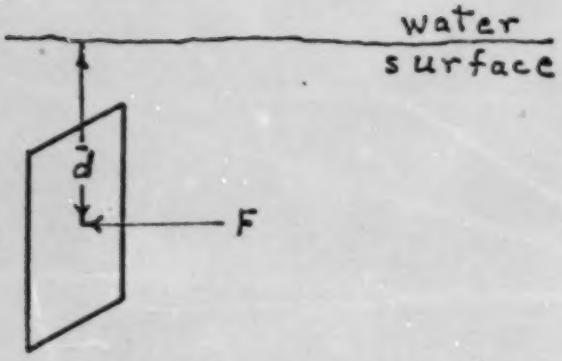
Horizontal Surfaces:



$$F = (\gamma)(d)(A)$$

$$lb = \left(\frac{lb}{ft^3}\right)(ft)(ft^2)$$

Vertical Surfaces:



$$F = (\gamma)(\bar{d})(A)$$

$\bar{d}$ = depth of centroid

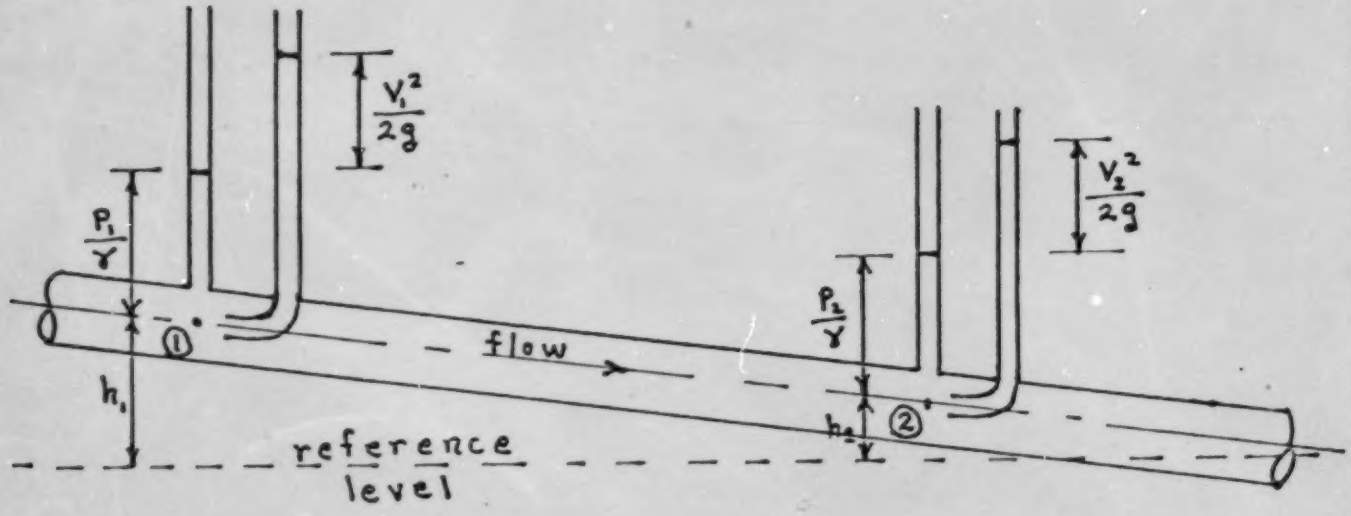
No. F.2.1

TYPES OF "HEADS"

Pressure Head = $\frac{P}{\gamma}$

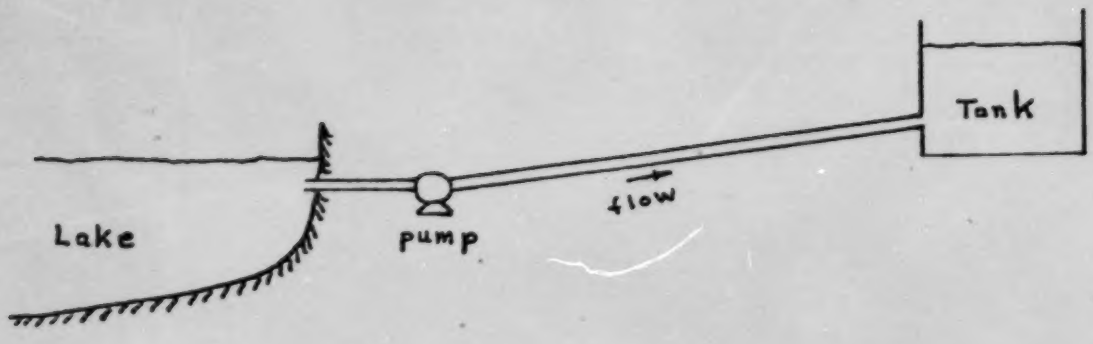
Velocity Head = $\frac{V^2}{2g}$

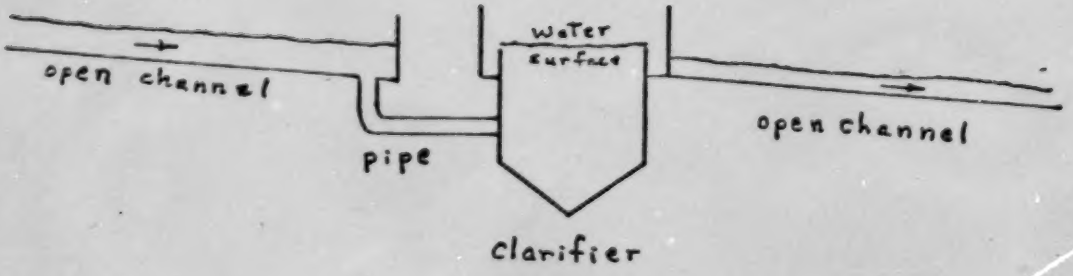
Position Head = h



No. G.2.1

ENERGY AND HYDRAULIC GRADE LINES

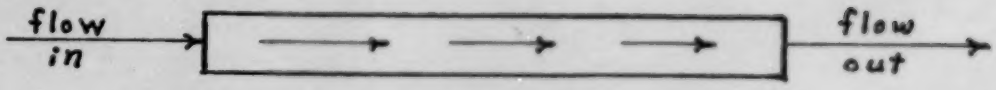




No. I.2.1

HYDRAULIC MODELS FOR TANKS

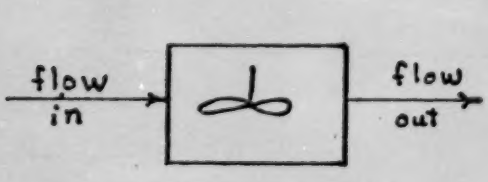
Plug Flow:



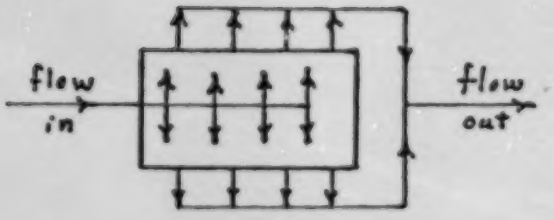
$$T = \frac{V}{Q}$$ for each liquid particle

No forward mixing occurs

Complete-Mixing:



or



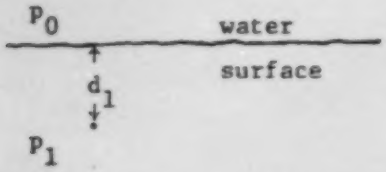
$$T_{ave} = \frac{V}{Q}$$

Some liquid stays in longer and some less time

Uniform composition in tank

PRESSURE-DEPTH RELATIONSHIPS

The pressure at any point in a body of water depends upon the depth below the surface and the pressure at the surface. If the surface pressure is atmospheric pressure, then the guage pressure below the surface depends only on the depth. The pressure increases at increasing depth because of the weight of water pushing from above. The pressure at any given depth can be calculated as follows:



Gage Pressure: $p_1 = d_1$

Absolute Pressure: $p_1 = p_0 + d_1$

where p_0 = pressure at surface

γ = specific weight of water

p_1 = pressure at depth d_1 below the surface

A consistent set of units must be used for calculations with these equations. If d_1 is in feet and γ is in lb/ft^3, then p_0 and p_1 must be in lb/ft^2 (psf).

Example: What would be the gage pressure and the absolute pressure at a depth of 15 feet below the surface of a pond if atmospheric pressure is 14.5 psi?

Solution:

i) Gage Pressure: $\gamma = 62.4\ lb/ft^3$ and $d_1 = 15ft$

$$\text{so } p_1 = (62.4)(15)lb/ft^2 = \underline{936\ psfg}$$

$$\text{or in psig: } p_1 = \frac{936}{144}\ psig = \underline{6.5\ psig}$$

ii) Absolute Pressure: $p_0 = 14.5 \times 144\ psf = 2088\ psf$

so $p_1 = (2088 + 936)\ psfa = \underline{3024\ psfa}$

and $p_1 = (14.5 + 6.5)\ psia = \underline{21\ psia}$

For calculations with a liquid other than water, the procedure is just the same except that the specific weight of that liquid is used for γ.

Handout No. F.1.1

PRACTICE PROBLEMS - 1

1) What would be the pressure in psig and in psia at a depth of 10 ft below the wastewater surface in a clarifier? Assume atmospheric pressure is 14.7 psi and the specific weight of the wastewater is the same as water.

2) What would be the gage pressure at a depth of 100 ft in sea water which has a specific weight of 64.0 lb/ft^3?

3) What would be the gage pressure and absolute pressure at the bottom of a tank containing water 25 ft deep if the local atmospheric pressure is 29.7 inches of mercury?

Handout No. F.1.2

CONVERSION FACTORS

	Given Unit	× Conversion Factor	= New Unit
Pressure	lb/sq. in.	144	lb/sq. ft.
	atmospheres	14.7	lb/sq. in.
	atmospheres	29.92	inches of mercury
	lb/sq. ft.	47.88	pascals
	lb/sq. in.	2.034	inches of mercury
	atmospheres	760	mm of mercury
	lb/sq. in.	0.1922	inches of water
Volume	cubic feet	7.48	gallons
	cubic feet	1728	cubic inches
	cubic feet	0.0283	cubic meters
	acre-feet	43,560	cubic feet
	gallons	3.785	liters
Area	square feet	144	square inches
	acres	43,560	square feet
	square meters	10.764	square feet
Mass	pounds	453.6	grams
	kilograms	2.205	pounds
Discharge	cu.ft./sec	0.646	million gals./day
	cu.ft./sec	449	gal/min
	million gals./day	694	gal/min
	cu.meters/sec	35.3	cu.ft./sec
Power	ft-lb/sec	550	horsepower
	horsepower	745.7	watts
	Btu/sec	1054	watts
Energy	Btu	778	ft-lb
	Btu	1055	joules
	calories	3.088	ft-lb
	ft-lb	1.356	foules

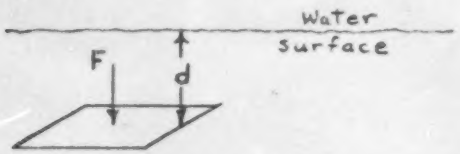
Note: To convert from a unit in the "New Unit" column to a unit in the "Given Unit" column, divide by the conversion factor.

Handout No. F.1.3

FORCE ON A SUBMERGED SURFACE

A force will be exerted due to water pressure on any submerged surface. The amount of force exerted on a surface can be calculated as follows:

1) Horizontal Surfaces:

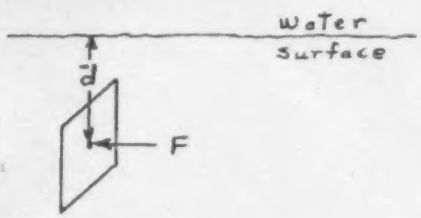


$F = PA$ and $p = \gamma d$

so $F = \gamma dA$

consistent units: γ in lb/ft^3, d in ft, and A in ft^2 will give F in lb.

2) Vertical Surfaces:



$F = \bar{p}A$, $p = \gamma d$, $F = \gamma \bar{d} A$

where $\bar{p}$ = pressure at the centroid of the area

$\bar{d}$ = depth of the centroid below the water surface

The centroid of a surface is its "geometrical center". The locations of the centroid for several common shapes are given on Handout No. F.2.2.

Note that the force on a vertical surface can be calculated if only the area of the surface and the depth of the centroid are known.

Examples:

1) What would be the hydraulic force on the bottom of a tank which is 20 ft wide and 80 ft long and contains water 15 ft deep?

Solution: $A = 20 \times 80\ ft^2 = 1600\ ft^2$
$d = 15$ ft

$F = \gamma dA = (62.4)(15)(1600)lb = \underline{1,497,600\ lb}$

2) What would be the hydraulic force on one of the 80 ft sides of the tank mentioned above?

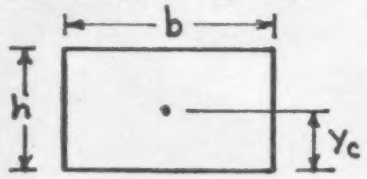
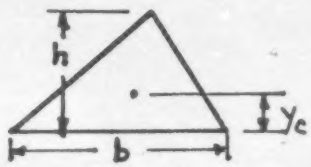
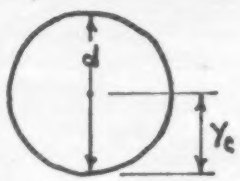
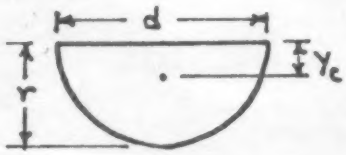
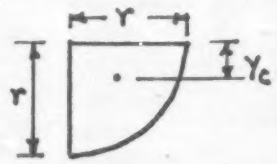
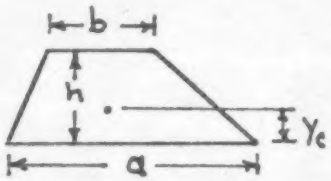
Solution: $A = 15 \times 80\ ft^2 = 1200\ ft^2$

from Handout F.2.2, $\bar{d} = \frac{15}{2} = 7.5$ ft

$F = \gamma \bar{d} A = (62.4)(7.5)(1200)lb = \underline{561,600\ lb}$

Handout No. F.2.1

PROPERTIES OF PLANE SURFACES

Shape	Sketch	Area	Location of Centroid
rectangle		$b\,h$	$Y_c = \frac{h}{2}$
triangle		$\frac{b\,h}{2}$	$Y_c = \frac{h}{3}$
circle		$\frac{\pi d^2}{4}$	$Y_c = \frac{d}{2}$
semi-circle		$\frac{\pi d^2}{8}$	$Y_c = \frac{2d}{3\pi}$
quadrant of circle		$\frac{\pi d^2}{16}$	$Y_c = \frac{4r}{3\pi}$
trapezoid		$\frac{h}{2}(a+b)$	$Y_c = \left(\frac{h}{3}\right)\frac{(a+2b)}{(a+b)}$

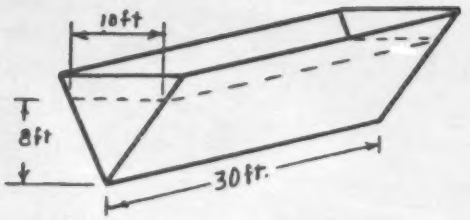
Handout No. F.2.2

PRACTICE PROBLEM - 2

1) a) What would be the hydraulic force on a submerged horizontal surface 10 ft by 20 ft if it is 12 ft below the water surface?

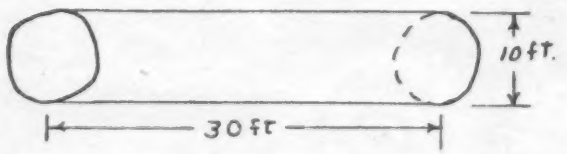
b) What would be the hydraulic force on the same surface if it were vertical with the 20 ft side lined up with the water surface?

2) What would be the hydraulic force on the triangular end of the tank shown below?



3) a) What would be the hydraulic force on the circular end of the tank shown below if it is half full of water?

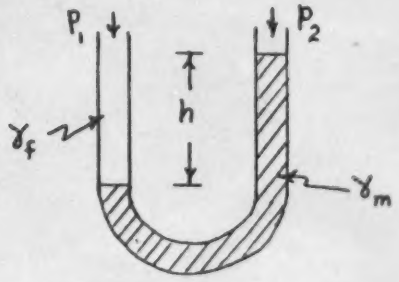
b) What would be the force if it were completely full of water?



Handout No. F.2.3

MANOMETERS

A u-tube manometer is a device which can be used to measure pressure differences. The variable actually measured is the difference in height of the manometer fluid in the two-legs of the manometer, as shown in the diagram below. The difference in pressure acting on the two legs of the manometer can then be calculated using the relationship between pressure and depth in a liquid, which has already been discussed. The pressure difference and height difference are related as follows:



$$P_1 - P_2 = (\gamma_m - \gamma_f)h$$

where γ_m = specific weight of manometer fluid

γ_f = specific weight of fluid whose pressure is being measured.

consistent units: h in ft, γ_m & γ_f in lb/ft^3,

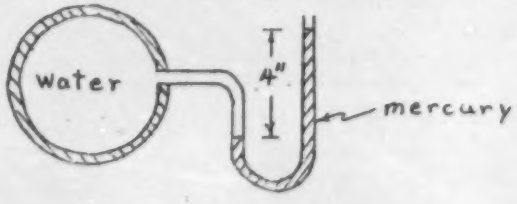
p_1 and p_2 in psf.

If one leg of the manometer is exposed to atmospheric pressure, then the manometer will read gage pressure acting on the other leg.

If the two legs of the manometer are connected to fluid at two different locations in a system, however, it will measure the difference in pressure between the two locations.

For measurement of large pressure differences a manometer fluid with high specific weight, such as mercury is used. For measurement of small pressure differences, a manometer fluid with a relatively low specific weight, such as an oil, is used.

Example: What is the gage pressure in psig in the pipe shown below? The specific gravity of mercury is 13.6.



Solution: $\gamma_m = (S.G.)(\gamma_{water}) = (13.6)(62.4)\ lb/ft^3 = 849\ lb/ft^3$

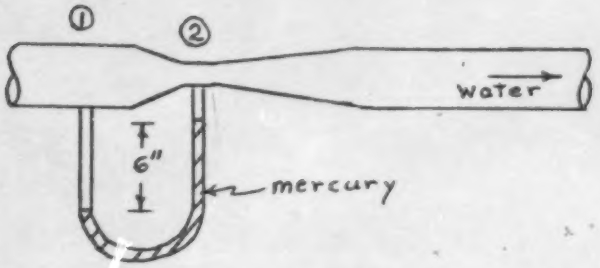
$P_{pipe} - P_{atm} = (849 - 62.4)(\frac{4}{12})\ lb/ft^2 = 262.2\ lb/ft^2$ gage

gage press in pipe = 262.2 psfg = 1.8 psig.

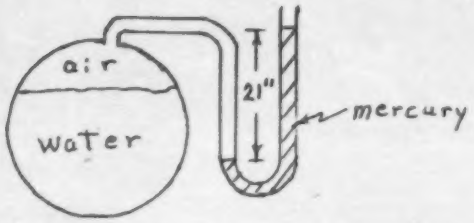
Handout No. F.3.1

PRACTICE PROBLEMS - 3

1) What is the pressure difference in psi between points 1 and 2 in the venture meter shown below?



2) What is the gage pressure in the tank shown below? For air use $\gamma = 0.12$ lb/ft^3.



3) What is the pressure difference indicated by a manometer with a height difference, h_1 of 7 inches if the manometer fluid has $\gamma = 184$ lb/ft^3 and the fluid being measured is water. Give your answer in psi and inches of water.

Handout No. F.3.2

CONSERVATION OF ENERGY

Basic Law of Physics: Energy is neither created nor destroyed except in nuclear reactions.

Application to Steady State Flow System:

$$\text{rate of energy flow into system} = \text{rate of energy flow out of system}$$

Note the similarity between this equation and the steady flow continuity equation for conservation of mass. With energy the situation is more complicated because energy can be converted from one form to another.

There are several possible forms in which the general energy conservation equation can be written. The one to be considered here is called Bernoulli's Equation. For the system shown below, Bernoulli's equation is written as follows:

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + h_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_2$$

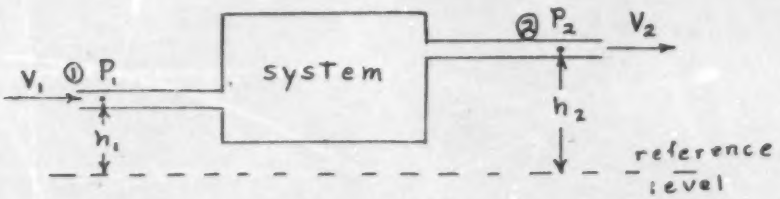
where P_1 & P_2 = pressure at points 1 and 2 respectively

V_1 & V_2 = velocity at points 1 and 2 respectively

$h_1 + h_2$ = height of points 1 and 2 respectively above some reference level.

γ = specific weight of the flowing fluid

g = acceleration due to gravity = 32.2 ft/sec^2



Bernoulli's equation is a special case of the general energy equation. It applies to a system with steady flow of a liquid, flowing from point 1 to point 2 with i) no pump or turbines in the system between 1 and 2, and ii) negligible frictional energy loss between 1 and 2.

For such a system, the rate of energy flow into the system per pound of water is given by the left hand side of the equation and the rate of energy flow out of the system per pound of water is given by the right hand ride of the equation.

The system could be a section of pipe or open channel, a tank such as a grit chamber or a clarifier, or any such item with flow in and/or out.

Further interpretation of each term in the equation is given in the next section.

Handout No. G.1.1

TYPES OF "HEADS"

Each of the terms in Bernoulli's Equation is referred to as a "head" as follows:

Pressure head = $\frac{P}{\gamma}$

interpretation:
i) Energy content of water per pound due to its pressure, P.
ii) Height of a column of water which will have pressure, P, at the bottom.

Velocity head = $\frac{V^2}{2g}$

interpretation:
i) Kinetic energy content of water per pound due to its velocity, V.
ii) Height of a column of water which has potential energy at the top equal to the kinetic energy of water with velocity, V.

Position head = h

interpretation:
i) Potential energy content of water per pound due to its height, h.
ii) Height of water above some chosen reference level.

Thus P_1/γ is the pressure head at point 1, $V_2^2/2g$ is the velocity head at point 2, etc.

If the following units are used (P in lb/ft^2, γ in lb/ft^3, V in ft/sec, g in ft/sec^2, and h in ft), then P/γ, $V^2/2g$, and h will all have units of ft, which can also be interpreted as ft-lb/lb.

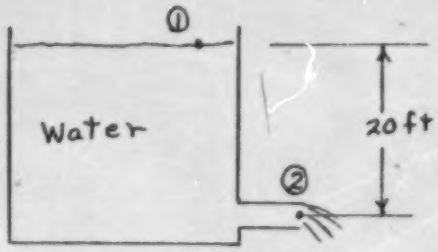
The Bernoulli equation, introduced in the last session, simply states that the rate of energy flow into the system at point 1 is equal to the rate of energy flow out of the system at point 2. The energy flowing in or out may be of three types, i) pressure energy (pressure head), ii) kinetic energy (velocity head), or iii) potential energy (position head). In other words, if one type of head is higher in the exit stream than in the inlet stream, then some other type of head must have decreased to make up for it (for any system to which Bernoulli's equation applies). For example, if the outlet is at a greater height than the inlet, then the pressure or velocity must be less at the outlet than at the inlet.

BERNOULLI EQUATION CALCULATIONS

The Bernoulli equation provides a way to calculate a pressure, velocity or height for an inlet or outlet stream if enough other information is provided about the inlet and outlet streams to the system.

Example:

What would be the velocity of water flowing out of the tank in the diagram below? Consider the pipe to be short enough that frictional losses can be neglected?



Solution: Choose points 1 and 2 as shown on the diagram.

Then $P_1 = P_2$ = atmospheric pressure = 0 gage pressure

$V_1 = 0$ (assuming that the tank level goes down slowly)

Choose the reference level for height to pass through point 2. Then $h_2 = 0$ and $h_1 = 20$ ft.

Substitute values into Bernaulli's equation

$$\frac{0}{\gamma} + \frac{0}{2g} + 20 = \frac{0}{\gamma} + \frac{V_2^2}{2g} + 0$$

solving for V_2 gives

$$V_2^2 = (2g)(20) = (2)(32.2)(20)\ ft^2/sec^2$$

$$V_2 = \sqrt{1288}\ ft/sec = \underline{35.9\ ft/sec}$$

The following hints are helpful in applying Bernaulli's equation to a problem.

1) P_1 and P_2 must both be gage pressure or else both must be absolute pressure.
2) In a reservoir or large tank the velocity is usually negligible compared with that in an outlet or inlet pipe, so in the reservoir or tank V = 0 can be used.
3) The pressure at the surface of a reservoir or open tank is atmospheric pressure or zero gage pressure.
4) The pressure at the outlet of a pipe exiting to the atmosphere is atmospheric pressure or zero gage pressure.
5) The velocity is the same at all cross sections in a constant area pipe for steady flow.

Handout No. G.3.1

PRACTICE PROBLEMS - 3

1) Use Bernoulli's equation to estimate the velocity of water as it reaches the bottom of a 35 foot waterfall.

2) Water is flowing uphill through a pipe of constant diameter. If the pressure in the pipe at the bottom of the hill is 20 psig, at what height would the pressure in the pipe be zero guage? Neglect frictional losses.

3) Consider water flowing through a horizontal reducer as shown below. If V_1 = 5 ft/sec, V_2 = 20 ft/sec, and P_1 = 20 psig, what would be the pressure, P_2 in psig, neglecting frictional loss?

Handout No. G.3.2

PUMP WORK AND EFFICIENCY

The energy input required to move water or raise it in height is often provided by a pump, usually by increasing the pressure of the water. The energy delivered to the water is always less than the energy required by the pump. The amount of difference is usually given by the efficiency which is related to the energy inputs as follows:

$$\text{Eff} = \frac{\text{Energy input to water}}{\text{Energy input to pump}} (100\%)$$

The energy inputs can be expressed as heads in ft or as ft-lb of energy per lb of water. These two sets of units are equivalent.

Example: What energy input to a pump with 85% efficiency would be needed in order to pump water from a reservoir to a plant inlet if a head of 40 feet of water is needed to transport the water?

Solution: The energy input required to the water is 40 ft of head or 40 ft-lb/lb.

From the equation above:

$$\text{Energy input to pump} = \frac{\text{Energy input to water}}{\text{Eff.}} (100\%)$$

so

$$\text{Energy input to pump} = \frac{(40 \text{ ft-lb/lb})(100\%)}{85} = 47 \frac{\text{ft-lb}}{\text{lb of water}}$$

Often the rate of energy input or power input required is of interest. It can be related to the head input and mass flow rate as follows:

$$P = \dot{m}H$$

where P = power input in ft-lb/sec

$\dot{m}$ = mass flow rate in lb/sec

H = head input in ft or ft-lb/lb

Example: What would be the horsepower requirement of the pump above if the flow rate of water to be pumped is 30 lb/sec?

Solution: $P = (30 \text{ lb/sec})(47 \text{ ft-lb/lb}) = 1410 \text{ ft-lb/sec}$

Converting to hp: $P = \frac{1410}{550} \text{ hp} = \underline{2.6 \text{ hp}}$

Note that the pump efficiency can also be given as

$$\text{Eff} = \frac{\text{Power input to water}}{\text{Power input to pump}} (100\%)$$

PRACTICE PROBLEMS - 4

1) a) What would be the energy input in ft-lb/lb required to an 80% efficiency pump in order to increase the head of a flow of water by 55 feet?

   b) What would be the horsepower requirement to the same pump for a flow of 100 lb/sec of water?

2) What is the efficiency of a pump if it delivers 8.5 horsepower to the water and requires 12 horsepower input to the pump?

3) What would be the head increase delivered to a flow of 80 lb/sec of water by a 75% efficient pump which uses power at the rate of 5 hp?

MODIFIED BERNOULLI'S EQUATION

The effect of friction loss and a pump in the system can be included in Bernoulli's equation by putting in a term for energy input by a pump on the input side and a term for energy loss from friction on the output side as follows:

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + h_1 + H_w = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + h_2 + H_f$$

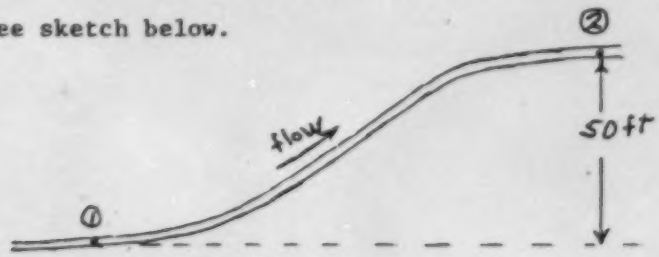
where H_w = Pump head = head input to water by a pump

H_f = Friction head = head loss due to friction

Examples:

1) Water is flowing uphill through a pipe of constant diameter. If the pressure in the pipe at the bottom of the hill is 40 psig, the frictional head loss in the pipe is 10 ft, and the hill is 50 ft high, what will be the pressure in the pipe at the top of the hill?

Solution: See sketch below.



For this system

$H_w = 0$ (No pump between points 1 and 2)

$H_f = 10$ ft

$V_1 = V_2$ (steady flow in a constant diameter pipe)

$h_1 = 0$

$h_2 = 50$ ft

$P_1 = 40$ psig $= (40)(144)$ psfg $= 5760$ psfg

Substitute into Bernoulli's Equation:

$$\frac{5760}{62.4} + \frac{V_1^2}{2g} + 0 + 0 = \frac{P_2}{62.4} + \frac{V_2^2}{2g} + 50 + 10$$

solve for P_2:

$$P_2 = 5760 - (62.4)(50+10) \text{ psfg} = 2016 \text{ psfg}$$

$$P_2 = \frac{2016}{144} \text{ psig} = \underline{14 \text{ psig}}$$

PRACTICE PROBLEMS - 5

1) For a particular trickling filter a velocity of 5 ft/sec leaving the rotary distributor nozzles is required to keep the distributor moving. If the frictional head loss through the distributor is 6 inches for a certain flow rate, what head of water is needed above the nozzles to keep the distributor moving?

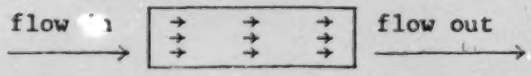
2) a) What energy or head input to the water would be required to pump water from a storage tank to the top of a 150 ft water tower if the frictional head loss in the piping is 5 ft? Consider the pressure to be atmospheric both in the tank at the top of the water tower and in the storage tank at the bottom of the water tower.

b) If the flow rate is to be 800 gpm and the pump has an efficiency of 75%, what horsepower would be needed for the pump?

HYDRAULIC MODELS FOR TANKS

Tanks with continuous flow in and out and various types of mixing are used for several operations in water and wastewater treatment, such as aeration tanks, clarifiers, rapid mix tanks, etc. The pattern of flow through the tank has an important effect on the performance of these processes. There are many possible flow patterns; two extreme cases will be considered here, plug flow and completely-mixed flow. The flow for many processes can very nearly be represented by one of these two. For other processes, the flow is actually something in between the two with characteristics of both.

Plug Flow:



For this pattern the liquid flow through the tank is orderly with no particle of liquid overtaking or mixing with any other particle. The particles of liquid pass through the tank in the same sequence they entered and each remains in the tank for the same length of time, called the "detention time", which can be calculated as follows:

$$T = \frac{V}{Q}$$

where T = detention time in minutes

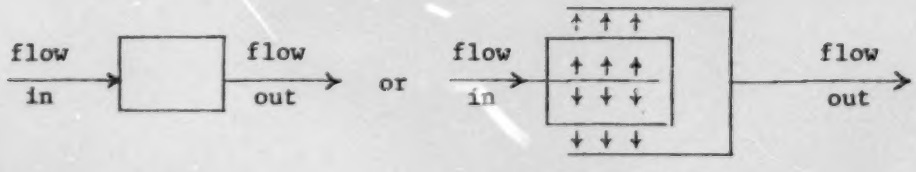
V = volume of tank in cubic feet

Q = volumetric flow rate through tank in cubic feet per minute

Long narrow tanks give approximately plug flow as indicated in the diagram above.

If a reaction is taking place in a plug flow reactor, then the composition of the liquid will be different at different points along the length of the tank. For example, if BOD is being removed from wastewater in a plug flow aeration tank, then the BOD concentration will decrease in the direction of flow.

Completely-Mixed Flow:



For this case the contents of the tank are well-mixed and uniform throughout, and incoming liquid particles become rapidly mixed into the tank. The exit stream will be identical with the contents of the tank. The average detention time will be V/Q, the same as for plug flow, but some liquid particles will be in the tank much longer and some for much shorter times, because of the mixing.

Completely-mixed flow is approximated in a tank having length and width nearly the same and intense mixing and turbulence as indicated in the diagram above. Spreading out the inlet and outlet flow, as indicated above, can also be used to give completely-mixed flow.

Even if a reaction is taking place in a completely-mixed tank, the contents of the tank will be uniform in composition and the same as the exit stream, but may be different in composition than the inlet stream.

Application to Activated Sludge

Plug Flow:

The conventional activated sludge process normally uses a type of aeration tank referred to as a "spiral roll" aeration tank. They are typically long, narrow tanks, and thus flow through them is approximately plug flow. Therefore the BOD is highest at the inlet end, the oxygen requirement is greatest at the inlet end, and variations in inlet flow rate and strength can have troublesome effects on the operation, because the changes are felt completely at the inlet end.

Completely-Mixed Flow

In recent years an interest in completely-mixed flow for activated sludge aeration tanks has developed. The main advantages are equalizing the oxygen requirement throughout the tank and greater stability for variations in inlet flow rate and strength. Such variations have less effect because the inlet flow is mixed in with the entire contents of the tank rather than just to a small inlet portion. This also allows a higher BOD loading per unit volume of aeration tank for completely mixed activated sludge plants than for conventional activated sludge plants.

SHORT CIRCUITING

Short circuiting refers to the flow of some incoming liquid through a tank without remaining for a satisfactory period of time. In an ideal plug flow tank, where all entering liquid passes through in order and stays in the tank for the same length of time, no short circuiting occurs. In any real tank some short circuiting occurs, but it can be minimized by proper design and operation.

Clarifier design and operation is an area where short circuiting is a major concern. Incoming liquid to a clarifier must remain in the tank long enough to allow suspended matter to settle out. If some of the incoming liquid "short circuits" out after a very short time, poor removal of suspended matter will result.

Some of the factors which cause short circuiting problems in clarifiers are as follows:

1) high inlet velocities
2) high velocities over the outlet weir
3) inlet and outlet placed too close together
4) action of wind on the liquid surface in the tank
5) uneven heating of the tank contents by sunlight
6) density difference between the incoming liquid and the tank contents
7) tank geometry.

The tank geometry is of major importance. The least short circuiting occurs for long, narrow, horizontal flow tanks and upflow circular tanks. More short circuiting occurs in short, wide, horizontal flow tanks and radical flow circular tanks.

ENERGY GRADE LINE - DEFINITIONS

1) Peizometric head (at station 1 in flowing water) = Pressure head (at station 1) + Position head (at station 1)

or, Peizometric head at (1) = $\frac{P_1}{\gamma} + h_1$

For open channel flow:

Peizometric head = height of liquid surface

For pressure flow:

Peizometric head = height to which water would rise in a vertical tube with its upper end open to the atmosphere and its lower end connected to a static pressure tap (opening perpendicular to the flow) at station 1. See the diagram below.

2) Total head (at station 1 in flowing water) = Peizometric head (at station 1) + velocity head (at station 1)

or, Total head at (1) = $\frac{P_1}{\gamma} + h_1 + \frac{1^2}{2g}$

For open channel or pressure flow:

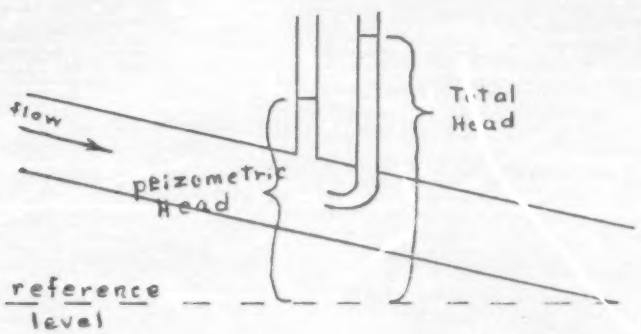
Total head = height to which water would rise in a vertical tube with its upper end open to the atmosphere and its lower end connected to a dynamic pressure tap (opening parallel to flow) at station 1. See the diagram below.

The hydraulic grade line and energy grade line are used in connection with a vertical view of a system through which water flows.

3) Hydraulic grade line - a line whose distance above the sketch of the system at any point is equal to the peizometric head at that point.

4) Energy grade line - a line whose distance above the sketch of the system at any point is equal to the total head at that point.

Sketching of hydraulic grade lines and energy grade lines is discussed in the next section.

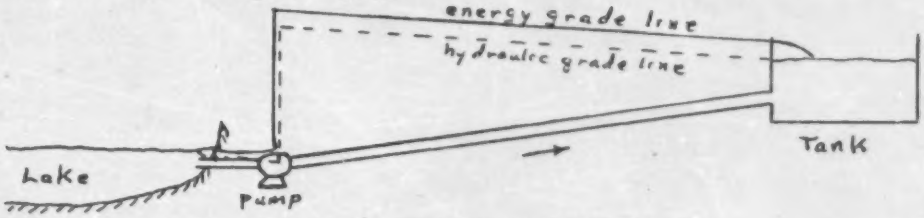


Handout No. I.1.1

ENERGY AND HYDRAULIC GRADE LINES

Energy grade lines and hydraulic grade lines show pictorially, the energy driving force available at various points along the flow path in a system. They can be sketched using an understanding of the relationships among the various types of heads and head losses. The following examples illustrate the procedure.

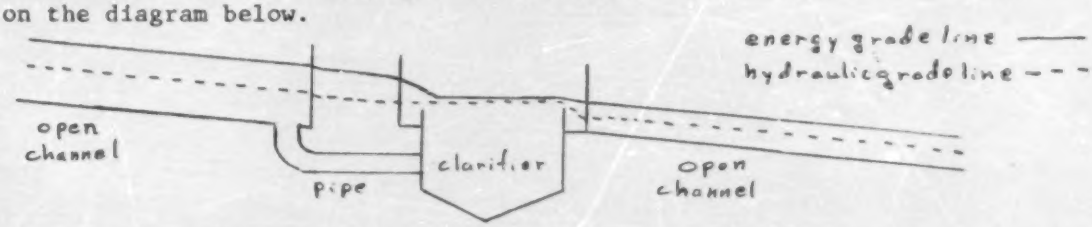
1) The energy and hydraulic grade lines for a water pumping system are shown on the diagram below.



The reasoning is outlined below:

Location in System	Energy Grade Line	Hydraulic Grade Line
inlet pipe to pump	goes down because of frictional head loss	goes down because of frictional head loss and because some pressure head is converted to velocity head.
pump	goes up because of pressure rise caused by pump	goes up because of pressure rise caused by pump.
pipe from pump to tank	goes down because of frictional head loss	goes down because of frictional head loss
flow from pipe into tank	goes down because velocity head is lost upon flowing into the tank	joins smoothly to liquid surface

2) The hydraulic and energy grade lines for flow through a clarifier are shown on the diagram below.



The hydraulic grade line is at the liquid surface for the open channels and tank. In the pipe, pressure goes up as position goes down. The energy grade line is above the hydraulic grade line by an amount $V^2/2g$ in the pipe and open channels.

Handout No. I.2.1

PRACTICE PROBLEMS - 6

Sketch the hydraulic grade line and energy grade line on each of the diagrams below. Be sure to clearly identify which is the hydraulic and which is the energy grade line.